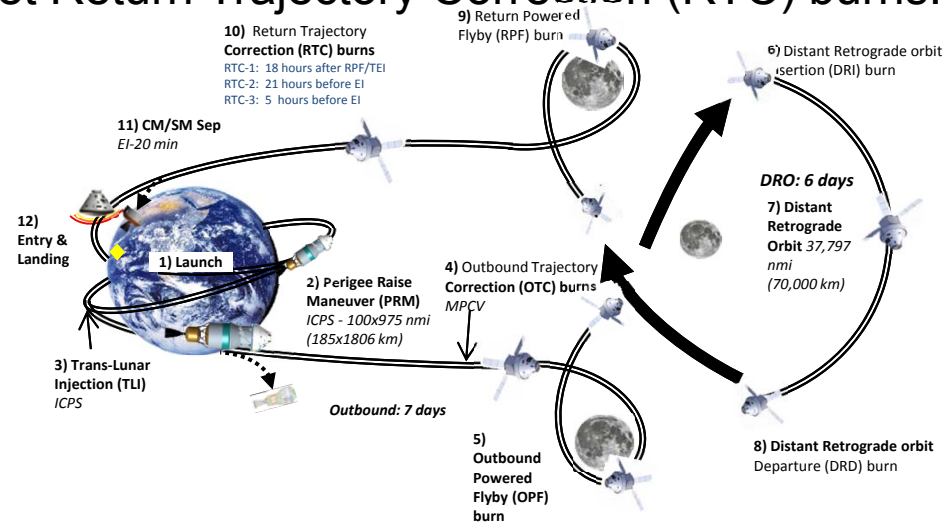
National Aeronautics and Space Administration

ISS Imagery Requirements for MPCV Optical Navigation

The MPCV Loss of Comm Problem

- **The Problem**
  - With a loss of communication with the ground or the DSN, MPCV loses its transponder based navigation capability and with it the capability to accurately target Return Trajectory Correction (RTC) burns.



- **The Solution**
  - MPCV is implementing an onboard Optical Navigation Solution to target RTC burns to make sure the crew meets their entry flight path angle requirement under contingency loss of comm conditions.

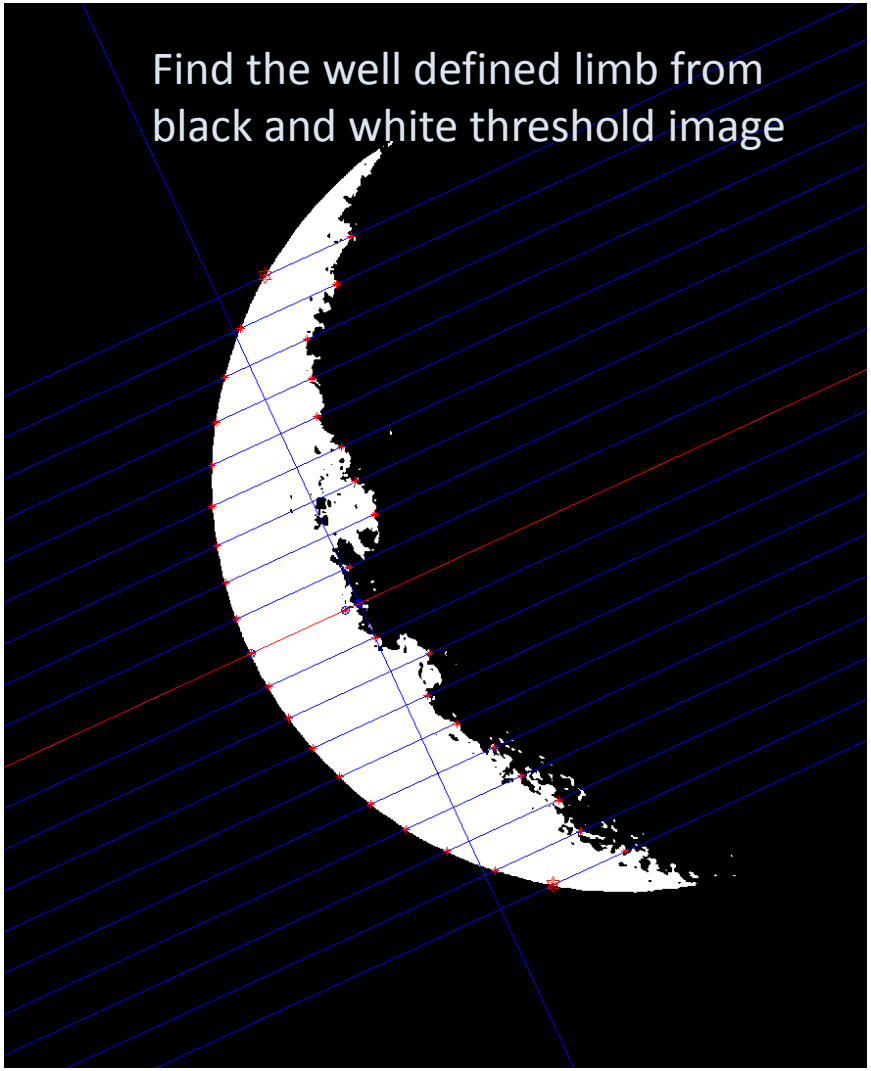
CEV Systems Requirements Document (SRD)

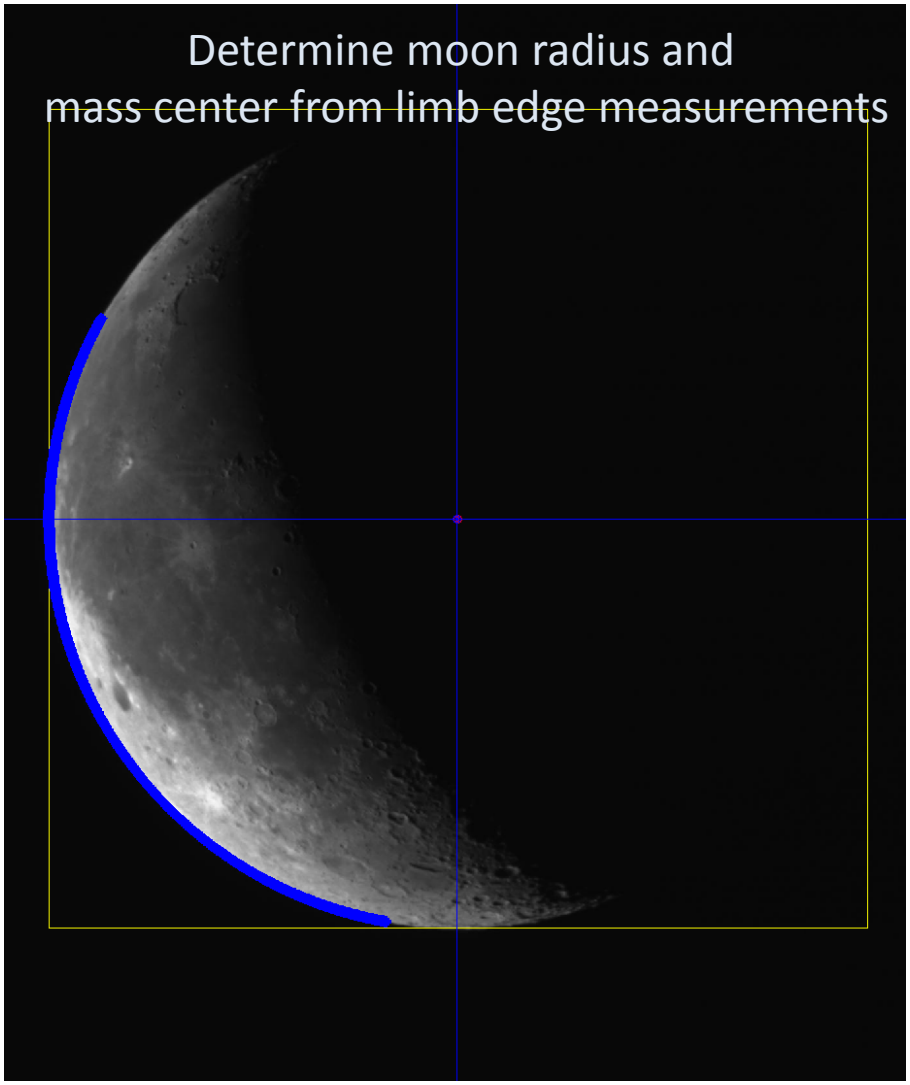
- **CA0416 – Orion Return Crew to Earth Independent of Communications with Mission Systems**
  - Orion shall return the crew to the Earth surface independent of communications with the Mission Systems during all mission phases.
  - EM2: This requirement applies at any point along the trajectory. Crew can be utilized.
- **CA0416-D - Orion Return CM to Earth Independent of Communications with Mission Systems - EM1**
  - Orion shall return the CM to the Earth surface independent of communications with the Mission Systems once the CM has been placed on the return to Earth trajectory.
  - EM1: This requirement applies once on a trajectory towards Earth (after Lunar Gravity Assist maneuver).

ISS Moon Imaging Experiment

- **MPCV Program Need**
  - An automated Optical Navigation solution is still developmental and requires truth data in the form of imagery from the field in order to validate its performance.
- **ISS Imagery Experiment Purpose**
  - Collect Moon Images from known Low Earth Orbit positions for Orion Optical Navigation Algorithm Refinement
    - Collect images over a span of at least one lunar cycle (29 days)
    - Eliminates atmosphere image distortion present in Earth based images
- **Supporting Organizations**
  - OZ: Dave Hornyak, Submit experiment requirements
  - GA: Debbie Korth, Orion MPCV Affordability Manager
  - DX: Steven Berenzweig, ISS Video and Photography
  - KX: David Bretz, Senior Imaging Scientist
  - KA: Gary Kilgo, Imagery Hardware
  - EG: Tim Straube, Orion GN&C

Example Image Analysis





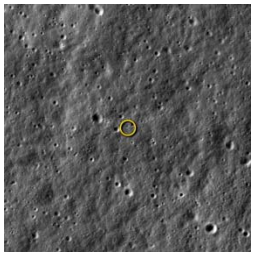
ISS Imagery Requirements

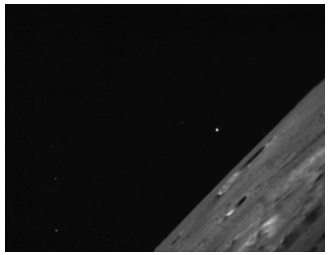
- **Requirements needed to validate optical navigation algorithms**
  - Need to know location of camera. Knowing the relative state between the moon and the image provides truth to compare the algorithms against.
  - The camera's clock needs to be calibrated to an accurate time source to accurately determine camera's true position when the image is taken.
  - Need a consistent fixed focus and focal length for all images taken. If the focus or zoom ring changes between the images, that changes the magnification of the image
  - Need imagery that is consistent with the expected optical navigation camera, 28 arcsec between pixels. (approximately 5 mp)
  - Subpixel measurement precision: Moon limb location to 1/3 pixel (1σ)

Imagery Already Looked At

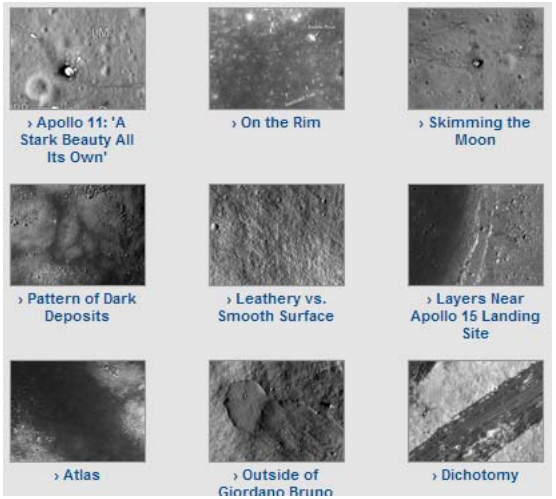
- **Moon imagery captured from ground cameras**
  - Earth's atmosphere proved to add too much distortion to the images

- **Lunar Atmosphere and Dust Environment Explorer (LADEE)**
  - the vast majority of the images were close up's of the moons surface
  - See examples here:
  - Did not have capability to image sunlit side of moon.





- **Lunar Reconnaissance Orbiter (LRO)**
  - the vast majority of the images were close up's of the moons surface
  - Two cameras:
    - Narrow FOV 2.85 deg
    - Wide FOV 92 deg



Imagery Already Looked At

- **Reviewed high resolution Moon photos from Imagery Online (IO)**
  - reviewed high resolution Moon photos from Imagery Online (IO) and other sources.
  - In the photos we reviewed, we did not have confidence the time tag in the photo's meta-data could be correlated to GMT within a known tolerance.
  - The camera's clock had not necessarily been routinely synchronized to an accurate time source for the existing photos
  - Focus setting not known to high precision.
  - Effect of scratch pane on images not characterized

Experiment Requirements

- **Timing**
  - Sample moon imagery on at least three days spanning the lunar cycle (29 days)
    - Can be days from different lunar cycles
    - Two image collecting sessions, half day apart, on each designated sampling day
  - Photo opportunity pass ~10 minutes (assumes viewing through oblique Cupola window)
  - 3.3 hours (for minimum set) + 1.1 hour for scratch pane characterization
- **Camera**
  - Camera and lens must be dedicated for the span of the experiment
  - Lens focus must not change during the experiment.
  - Camera clock must be correlated to accurate time source
    - Used to determine ISS position when image is captured
  - Camera to be mounted
    - Reduces camera shake
- **Schedule**
  - Need imagery in time to incorporate into MPCV EM1/2 CDR (October 2015)
  - Need ISS imagery by April to incorporate into review

Candidate Optical Navigation Cameras

Candidate Equipment Characteristics

Camera Vendor	IDS	PixeLink	Nikon D3*
Sensor Manufacturer	Aptina Sensor	ON Semiconductor	N/A
Shutter type	Electronic rolling	Electronic Global	Mechanical focal plane
Sensor size (mm)	5.7 x 4.28	12.44 x 9.83	35.9 x 24
Lens focal length	16mm	35mm	60mm
Pixels	2592 x 1944 (5mp)	2592 x 2048 (5mp)	4256 x 2832 (12mp)
Field of View (FOV) deg	20.2 x 15.2	20.2 x 16	33.4 x 22.5
Instantaneous FOV (arc-sec)	28	28	28.25**

*ISS camera. Used as alternative if our own cameras can't be placed on board

**Matching iFOV of proposed optical navigation camera is the driver

Constraints or Issues

- **Shooting through cupola windows**
  - Unknown optical quality
    - Different windows or section of same window may have their own aberrations
    - Moon will appear through different sections, portions and angles of glass
  - Vacuum-glass-air transitions
- **Shooting through scratch panes**
  - Image quality will be reduced
  - Possibility of piggy-backing on the IMAX work
- **Moon visible for 8-10 minutes per pass**
  - Plan to use Cupola oblique windows
  - Are other windows on board available with good views of the Moon?
- **Limited range of distance between LEO and Moon**
- **If MPCV supplied camera(s) can't be qualified and flown:**
  - ISS lens and camera calibration data not available
  - Difficult dedicating an ISS camera for experiment duration

Crew Time Required for Experiment – Desired Approach

- **Minimum estimated time to complete one day (two sessions per day) of moon imagery capture**
  - 67 mins (shooting through scratch panes and setting up/taking down camera hardware after each shooting day)

- **Minimum estimated time to complete all imagery capture every four days over entire lunar cycle (a total of 16 sessions)***
  - 9 hours (shooting through scratch panes; setting up/taking down camera hardware after each shooting day)

- **Crew member typically gets faster at performing tasks after executing procedures after first time**

- **Request one crew member to be dedicated for the duration of the experiment**

*** Detailed breakdown of Crew activity times available**

Crew Time Required for Experiment – Minimum Acceptable Set of Images

- **Minimum estimated time to complete one day (two sessions per sampling day) of moon imagery capture**
  - 1.1 hr (67 mins) per sampling day
    - assumes scratch panes are left in place
    - setting up/taking down camera hardware after each shooting day
    - estimate will increase if camera must be stowed between sessions on the same sampling day

- **Minimum estimated time to complete all imagery capture on at least three days spanning the lunar cycle (29 days)**
  - 3.3 hours (assuming shooting through scratch panes; setting up/taking down camera hardware after each sampling day)

- **Scratch Pane Characterization photos**
  - Take photos of Moon through different areas of a window
  - Trying to detect any change in apparent Moon diameter or distortion due to local scratch pane irregularities
  - 1.1 hours per window (One window minimum)

Summary

- **MPCV has a requirement to be able to reliably return home in the event of loss of communications**
- **The MPCV Program needs a space based platform to collect Moon images from a known position to help validate its optical navigation approach**
- **The MPCV Program endorses the need for these ISS-based moon images, and sponsors the proposed activity.**
- **Camera resolution should be equivalent to the type to be used on board MPCV**
- **ISS is an excellent platform from which low Earth orbit Moon imagery can be collected using a suitable camera**
- **Total crew time estimate for minimum set :**
  - 4.4 hrs = 1.1 hr ($_{SP\ test}$) + 3 sampling days * 1.1 hr/sampling day)